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Center for Army Analysis

SPECIAL OPERATIONS FORCES TACTICAL ENERGY RESOURCE (SOFTER)

DECEMBER 2004

CENTER FOR ARMY ANALYSIS
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13. ABSTRACT *(Maximum 200 Words)*
The US Army is continuing to fight the global war on terrorism in remote areas of the globe. Army Special Operations Forces (SOF) and light infantry troops are deployed in remote areas in both Operation Iraqi Freedom and Operation Enduring Freedom as well as other places to provide humanitarian assistance (e.g. January 2005 tsunami relief efforts in southeast Asia). To support these remote area missions, Army leadership is leveraging new renewable power and energy technologies to provide value added to the soldier. This work examines and analyzes the power and energy required by SOF personnel to run their communication electronics. Disposable batteries, rechargeable batteries, fuel cells and solar panels are reviewed in this work which also provides a comparison of alternatives. This study also provides a cost-benefit analysis of the economic factors involved with SOF power and energy alternatives and includes a disposal cost analysis as required to support environmental protection and enhancement (Army Regulation 200-1).

14. SUBJECT TERMS
Keywords: BA-5590 (disposable battery), BB-390 (rechargeable battery), BB-2590 (rechargeable battery), Direct Methanol Fuel Cell (DMFC), thin-film photovoltaics (PV), renewable energy, Special Operations Forces (SOF), Army Materiel Command Field Assistance in Science and Technology (AMC-FAST)

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SPECIAL OPERATIONS FORCES TACTICAL ENERGY RESOURCE (SOFTER)

SUMMARY

THE PROJECT PURPOSE

This work provide a cost-benefit analysis that addresses current and future power and energy alternatives for Special Operations Forces personnel operating in remote areas. Changes in Army battery policy are preparing deployed forces to employ more rechargeable technologies for both peacetime and warfighting deployments. USSOCOM has been at the forefront of the rechargeable battery analysis for Special Forces along with CECOM since the late 1990's.

THE PROJECT SPONSORS: AMC-FAST Science Advisors to USAREUR and USSOCOM; Dr. John Johnson and Mr. Bill Andrews

THE PROJECT OBJECTIVES are to:

(1) Learn more about the technical complexities of rechargeable and renewable power and energy resources

(2) Analyze the costs and benefits of employing various power and energy alternatives which support Army missions in remote areas

(3) Analyze disposal costs for end-of-life-cycle batteries and battery components.

(4) Elicit operational feedback from soldiers in the field regarding the value added of rechargeable batteries and remote electricity generation for their remote missions

THE SCOPE OF THE PROJECT

Analyze two notional mission case studies provided by USSOCOM HQ; (1) Direct Action missions and (2) Special Reconnaissance missions analyzing only the associated communication electronics power and energy requirements associated with each.

THE MAIN ASSUMPTION

USSOCOM's analytical report entitled Special Operations Forces Mission Analysis; Power Requirements by Mr. Randy McCune, Office of Special Technology (OST); August 2001 is assumed to be the definitive work on this topic and from which this report relies on for mission analysis data and for battery usage profile data.

THE PRINCIPAL FINDINGS are**:**

• Reduced SOF portable battery weight (and battery volume) can be achieved with current technologies for specific SOF missions on the order of:
– at least 50% less battery weight and 50% reduced battery volume
– weight and volume reductions on a "per man" basis show similar results
• Numbers of batteries can be significantly reduced provided the appropriate remote power technologies are in place – along with rechargeable battery planning
• 20 year, life cycle costs illustrate that solar is ~1/5th the cost of disposable batteries and ~1/3rd the cost of a tactical fuel cell.
• The difference in cost between 60w and 120w of solar array material (additional up-front capital cost of $1,000, for poor solar locations) represents less than 10% of the total 20-year life-cycle cost of the rechargeable battery system.
• Disposal costs for the disposable BB-5590 are ~11% of total life cycle battery costs – rechargeables are 2-3%
• Operational feedback from soldiers is supportive of rechargeable battery policy and solar recharging alternatives

THE PRINCIPAL RECOMMENDATIONS are:

(1) AMC-FAST study sponsors leverage their positions as "field assistance teams in science and technology" to collect first order data and feedback on a regular basis from troops-in-the-field and provide this data to analytical organizations for critical analysis and review.

(2) Provide a continuing economic life-cycle analysis of renewable power and energy generation sources on a yearly basis. This is needed as battery technologies improve and renewable power source manufacturing increases efficiencies and lowers cost through mass production. (note: Department of Energy studies indicate that the cost of photovoltaics, (as only 1 example) are reduced "on average" by 5 percent per year. Similarly thin-film photovoltaic product efficiencies have increased by nearly 2 percent each year since 1999.

(3) Continue to explore stored energy alternatives as they become commercially available but to also recognize their shortcomings for military applications.

THE PROJECT EFFORT was conducted by Hugh W Jones, Resource Analysis Division, Center for Army Analysis.

COMMENTS AND QUESTIONS may be sent to the Director, Center for Army Analysis, ATTN: CSCA-RA, 6001 Goethals Road, Suite 102, Fort Belvoir, VA 22060-5230

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1 INTRODUCTION

1.1 Special Operations Forces Tactical Energy Resource Analysis (SOFTER)

Unclassified

December 2004

Sponsors: AMC Science Advisors for USAREUR and USSOCOM

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Dr. Charles R. Leake
(deceased)

Unclassified

Figure 1. Special Operations Forces Tactical Energy Resource Analysis (SOFTER)

This effort was sponsored by the Army Materiel Command and its Forward Assist for Science and Technology teams at US Army Europe (Dr. John Johnson) and Mr. Bill Andrews at MacDill AFB (US Southern Command).

1.2 Agenda

- Problem Statement
- Background & Milestone Chart
- Purpose & Objectives
- Scope
- Essential Elements of Analysis and Measure of Effect
- Approach
- Methodology
- Assumptions
- Battery Analysis
- Cost Benefit Analysis
- Battery Disposal Analysis
- Operational Feed-back
- Summary
- Recommendations

Figure 2. Agenda

Dedication. This paper is dedicated to the memory of Dr. Charles R. Leake (1930 – 2004), distinguished colleague, analyst and friend who passed away after a long fight with cancer. Dr. Leake provided many analytical insights to this topic and worked tirelessly to provide much of the report's content and final framework.

1.3 Problem Statement

GEN Paul Kern[1] (CG, Army Materiel Command): " The Army's biggest materiel problems are (1) fuel, (2) water (3) *batteries* . . ."

Mr. Mark O'Konski[2]: Director, Logistics Transformation Agency (LTA)"The Army has to find *cheaper* ways to power the remote battlefield."

USSOCOM Report[3]: The two overriding factors that influence Special Operations Forces power planning are *weight* and *cost*. To reduce these factors in the future would greatly enhance the overall capability of SOF soldiers and their missions[2].

Summation: Weight and cost of energy sources are identified as drivers for Special Forces power planning. The impacts of weight and cost on tactical energy storage given changing technologies needs to be explored as does the associated costs for providing the remote power in the first place.

[1]Briefing to the Corps of Cadets at the United States Military Academy, West Point, NY on September 9, 2002

[2]14 November 2002 feedback from CAA briefing to LTA

[3]SOF Mission Analysis; A Special Power Requirements Report for USSOCOM, Prepared by the Office of Special Technology (OST), Randy McCune; August 2001

Figure 3. Problem Statement

Battlefield tactical power for deployed forces is a premium commodity. Major commands like the Communications and Electronics Command at Ft. Monmouth, New Jersey and the Army Materiel Command at Ft. Belvoir, Virginia are looking at various alternatives to help produce power and energy for tactical applications. Additionally, research based organizations such as the Defense Advanced Research Projects Agency (DARPA) and the Army Research Labs under the Research and Development Command continue to test and evaluate prototype systems having the promise of reducing logistics footprint while simultaneously having the ability to better serve the soldier.

GEN (ret) Paul Kern in comments made to AMC's Integrated Project Team for Power and Energy stated on 5 November 2004 "I will argue that electrical power will be the single most important problem of the 21st century. If oil continues its upward spiral to greater than $55 per barrel, we as an Army may not be able to afford to fight in the future."

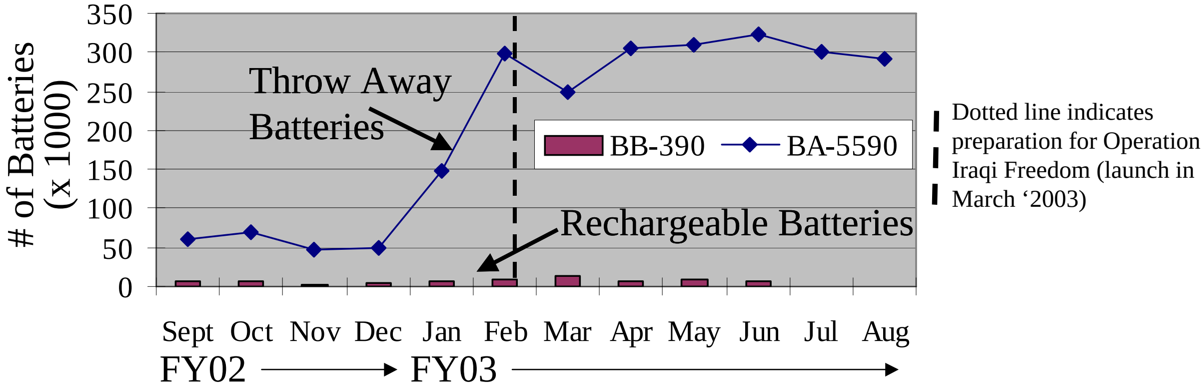
Forward Operating Bases (FOB) and Tactical Operating Centers (TOCS) in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) use JP-8 powered generators for prime power and similarly powered gensets for some missions in the field. The power range of these gensets is quite large, and includes small 5kW through and including 1,000kW generators.

However, the focus of this paper is on soldier power which is on a scale of not kilowatts, but watts. Light units such as Special Operations and Airborne forces have been using 21st century prototypical power generation devices since 2003 to include solar powered arrays and small fuel cells. The remainder of this paper will discuss the benefits and costs of these newer alternatives versus the legacy systems more familiar to the Army, namely small JP-8 generators (< 5kW).

1.4 Rechargeable vs. Disposable Demand Disparity*

Army Battery Demand Histogram

Driven by policy, legacy and battery physics, the overwhelming demand is still for disposable batteries.



- Cumulative purchase costs for BA-5590 (Li) @ $77ea from Sept '02 to Aug '03 is ~ $190M
- BA-5590 > 70% of batteries in inventory (primary radio battery for PRC-119; SINCGARS)
- Rechargeable monthly demand has remained constant even though demand for the "throw-away" BA-5590 has tripled
  - BB-390 is heavier than BA-5590
  - BB-390 has fewer Amp Hours
  - Logistics planning for rechargeables is lagging

*Chart courtesy of Logistics Readiness Command

Figure 4. Rechargeable vs. Disposable Demand Disparity

This chart illustrates the problem from a demand point of view. If indeed the power and energy problem is as serious as Army management claims, one has to wonder why the Army is increasing the numbers of batteries in Army inventories.

The first reasons of course, is that in time of war, current technology is the status quo. This minimizes risk to the soldier and allows him to employ the same batteries that he/she used in training. Although the battlefield has been a fertile proving ground for electronic equipment, medical advancements, weapons technologies and advancements in soldier training – there are few alternatives to stored energy technologies.

The second reason is of timeliness. Even though, as the reader will see in the following pages, Army policy is changing to mandate the use of rechargeable batteries in all training and where feasible in wartime, policy has not yet caught up with reality.

Lastly, the soldier has to feel comfortable with using rechargeables. Soldiers have not as yet (with some Airborne exceptions) warmed to the idea of rechargeables. For this to occur, soldiers need to understand that although on the surface it appears "easier" to draw disposables from supply as opposed to recharging, soldiers will eventually eliminate the supply chain required for disposables.

Although this report will provide an in-depth review of costs, the fact remains that rechargeables have less energy than disposables and that soldiers have to spend additional time in their busy schedules to perform the “recharging”. As anyone with a cell phone knows, recharging needs to be a planned event and this takes time.

1.5 Background & Milestone Chart

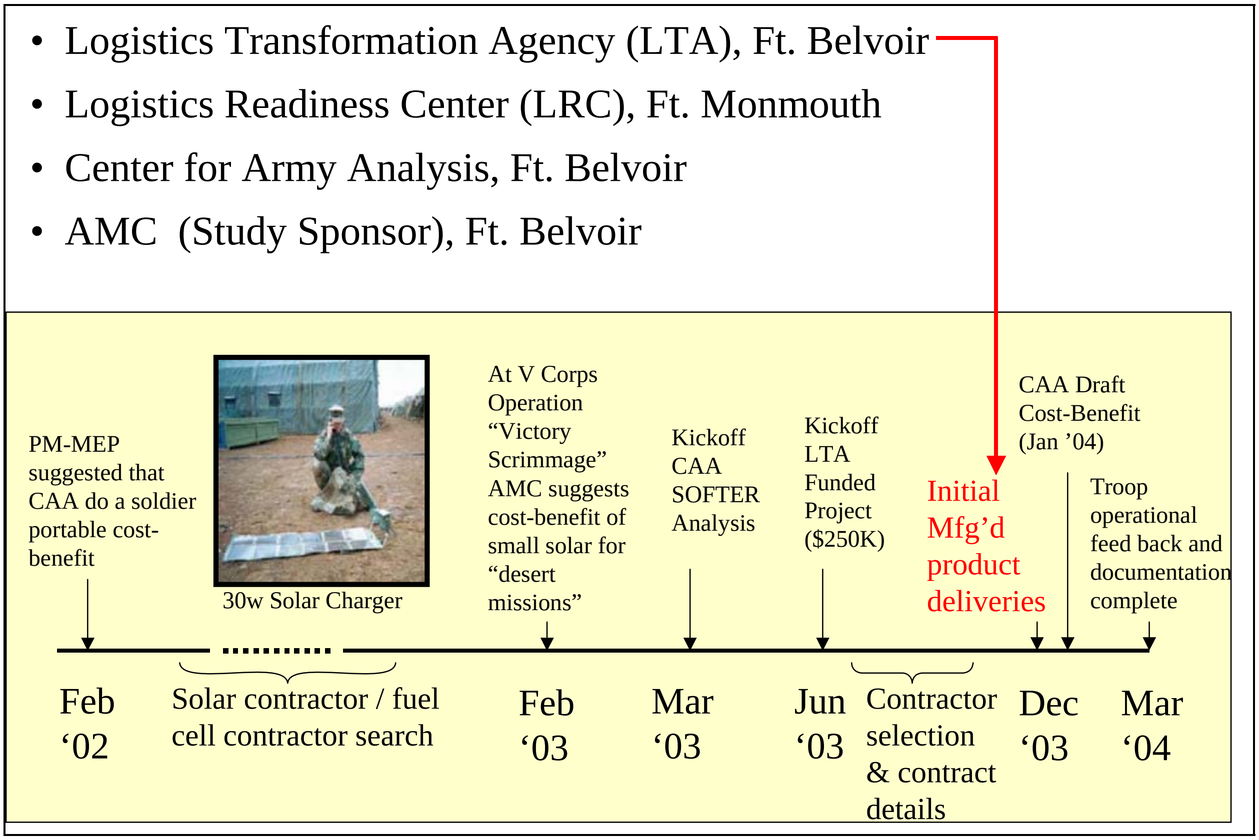


Figure 5. Background & Milestone Chart

This work was done in conjunction with a number of other Army organizations to include the Logistics Readiness Command (Ft. Monmouth, NJ), Logistics Transformation Agency (Ft. Belvoir, VA), the Army Materiel Command's Field Assistance in Science and Technology (AMC-FAST), the US Army Special Operations Command (HQ USASOC, Ft. Bragg, NC), US Army Communications-Electronics Research and Development Center (CERDEC; Ft. Belvoir, VA), Natick Soldier Center (US Army RDECOM; Natick, MA), 3/504th Parachute Infantry Regiment (82nd AB Division, XVIIIth AB Corps, Ft. Bragg, NC) and the Marine Corps Systems Command Expeditionary Power Systems Command (Quantico, VA).

Private industry partners included Giner Electrochemical (Boston, MA) for fuel cell manufacturing, Bren-tronics Inc. (Commack, NY) for battery manufacturing and Global Solar Energy (Tucson, AZ) for thin-film solar array manufacturing.

1.6 Army Rechargeable Battery Policy

Background

Dated 10 July, 2003 (update to policy of 29 August 1997)

Memorandum from ODCSLOG (DALO-SMM)

- All units (except those using fewer than 12 batteries per year) will use rechargeable batteries for military operations including training and garrison duty.
  - Peacekeeping operations shall also maximize the use of rechargeables
  - Funding for rechargeable batteries and chargers will come from the unit's Operation and Maintenance Army (OMA) funds.
  - Rechargeables and their logistics planning shall be incorporated into units as a viable alternative power source during wartime
- *Exceptions to this policy*
  - *Primary batteries will be used when recharging is not practical (remote locations) and temperature exceeds operational range (-40F to +120F)*
  - *This policy does not apply to a unit's frontline wartime operations*

Figure 6. Army Rechargeable Battery Policy

In earlier versions of Army battery policy, rechargeables were never mentioned. Since 1997 however, rechargeables have gone from "back burner" to today's Army's policy which centers around rechargeables.

1.7 Army Battery Disposal Policy

Background

- Environmental Protection Agency sets policy for hazardous waste.
- Army complies with EPA environmental policy guidelines through AR-200-1 (with technical, bulletin updates from CECOM)
- Army policy for battery disposal OCONUS is to police up all batteries and to comply with the local authorities (or, as in the case in IRAQ – most batteries end up in marked landfills)
- BA-5590 (lithium-sulfur dioxide), BB-2590 (lithium-ion) and BB-390U (nickel-metal hydride) batteries are considered non-regulated waste by EPA and are usually recycled. The states of AK, CA, MN, RI and WA require 100% recycling of all batteries.
- Other batteries like *lead*-acid, *manganese* dioxide and nickel *cadmium* are also regulated to control wastes classified by EPA as hazardous
- CECOM provided Army battery disposal costs of $4 per lb.

Figure 7. Army Battery Disposal Policy

Army battery disposal policy is set forth primarily in Army Regulation 200-1; *Environmental Protection and Enhancement*. It outlines how the Army complies with the Environmental Protection Agency (EPA) criteria for "Municipal Solid Waste Landfills" as defined in 40 CFR 258 or their state-approved program.

It is the Army's goal to use, generate, transport, store, handle, and dispose of oil and hazardous substances (such as lead-acid batteries) in a manner that protects the environment and public health. Battery disposal (usually by burning at high temperatures) is a pollution prevention measure endorsed by AR 200-1 (pg 24, Chapter 10) which states;

"The Army's primary pollution prevention goal is to reduce reliance on products or processes that generate environmentally degrading impacts to as near zero as feasible. This will reduce or avoid future operating costs and liability associated with environmental compliance and cleanup, and from unnecessary generation of waste; as well as avoid disruption of mission operations due to regulatory compliance problems."

Army environmental program in foreign countries ensures compliance with applicable standards and regulations which adequately preserve, protect, and enhance environmental quality and human health and ensure long term access to the air, land and water needed to protect U.S. interests.

1.8 Literature Search

The following items were found that related to the topic of using photovoltaics or enhanced batteries to charge electronic equipment in remote areas. They are:

1. Soldier Portable Photovoltaic Power Pack (SP4), by Steve Slane, Communications Electronics Research, Development and Engineering Center (CERDEC), August 2004
2. Special Operations Forces Mission Analysis; Power Requirements by Mr. Randy McCune, Office of Special Technology (OST); August 2001
3. Headquarters FORCES Command; Battery Management Program (for Vehicular Lead-Acid and Communications Electronics Batteries) by Deputy chief of Staff for Logistics; June 1999
4. Battery Survey of Army Special Operations Forces by Mr. Mike Miller and Mr. Fee Chang Leung, Communications and Electronics Command; July 1998
5. Special Operations Forces Aluminum Air Battery for Communications Equipment Phase 2 Final Report by CTI, INC., February 1998
6. Assessment of Special Forces Power Source Requirements by Thomas Abrials and Craig McCordic, CTI, Inc., January 1993
7. Special Operations Forces (SOF) Lightweight Solar Panel Battery Charging System by Loraine Parr, Army Development and Employment Agency (ADEA), June 1988

Figure 8. Literature Search

Special Operations Forces have produced a report entitled SOF Mission Analysis; Power Requirements (dated 6 August 2001). Data from this report is used as a baseline and point of departure in this report (SOFTER) with permission of the author and the SOCOM AMC-FAST Science Advisor for this project. The author at the conclusion of the SOF Mission Analysis; Power Requirements report notes that

"solar panels (charging) is fairly slow and time consuming. In addition, if your mission is to be conducted at night, then your source has ceased to exist."

Although it is still impossible to employ photovoltaics (PV) at night, thin-film PV has become much more powerful and reliable over that past 4 years.

Thin-film photovoltaic arrays are foldable solar panels made from either amorphous silicon materials or from other composite materials such as Copper-Indium-Gallium-DiSelenide (CIGS). The earliest document found on using PV to charge Army batteries was in September, 1988 under the title "Special Operations Forces (SOF) Lightweight Solar Panel Battery Charging

System”. In that case, a SOVONICS amorphous silicon PV array was manufactured and tested at Ft. Lewis, Washington to support power in remote areas. Testing of the PV by both the US Army Materiel Commmand (AMC) LABCOM and the US Army Development and Employment Agency (ADEA) was completed with positive results achieved at the John F. Kennedy Special Warfare Center and School (TRADOC). Battery charging times were noted to be good. No further evidence is available to prove or disprove that any further testing was accomplished.

1.9 Purpose

• Provide a cost - benefit analysis to the Army's Materiel Command which highlights the strengths and weaknesses of renewable power and energy storage technology applications.

Objectives

- Perform a cost-benefit analysis of prototype solar chargers recently purchased by the Logistics Transformation Agency (LTA)
- Analyze associated battery *weight* and *cost* from 2 notional case studies evaluating current capability remote mission energy storage versus newer technologies possessing the potential for energy storage added value
    1. Use a documented, notional case study of SOF missions provided by USSOCOM for battery weight trade-offs
    2. Develop a life cycle cost-benefit analysis to provide analytical underpinning for Army prototype projects using solar and fuel cells for recharging batteries.

Figure 9. Purpose

The purpose and objectives for this study are listed above.

1.10 Scope

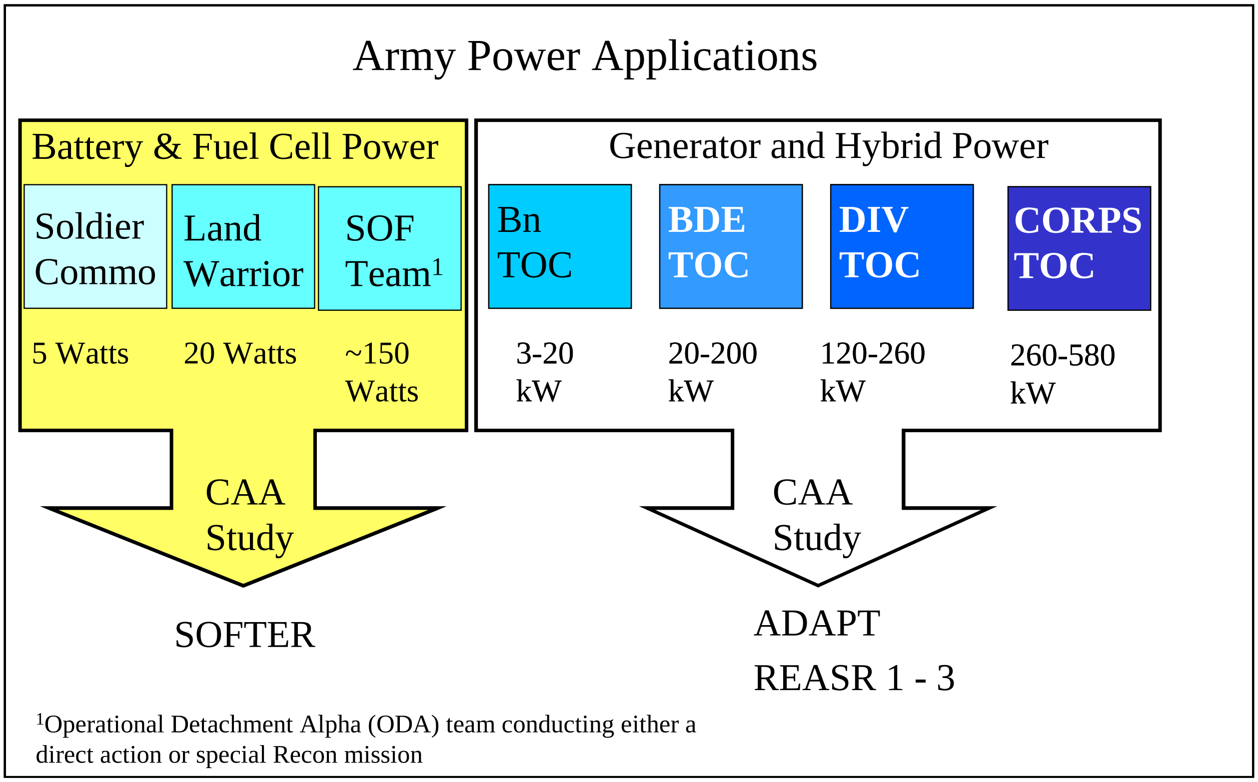


Figure 10. Scope

The scope of Army soldier power addressed in this report falls in the range of 5 to 150 watts of power. Higher levels of power have been previously addressed in the CAA studies entitled

- The Analysis of Deployable Applications of Photovoltaics in Theater (ADAPT) published in July 2000
- Renewable Energy Analysis for Strategic Responsiveness (studies 1 through 3) published in 2001, 2002 and 2004 respectively).

1.11 Scope (continued)

Notional SOF missions for energy weight storage calculations

- Direct action mission (16 man seal team, 5 day mission)
- Special reconnaissance mission (6 man team, 11 day mission)

Energy cost and operational feedback

- Communications equipment (heaviest battery weight)
- Constant $$$
- 20 year timeframe: 2003 – 2023
- Iraq latitude in summer for good solar capability
- Northern Germany latitude in winter for poor solar capability
- Iraqi Theater for operational feedback (by March 2004)
  - 5th Special Forces Group
  - 82nd Airborne Division, XVIIIth AB Corps

Figure 11. Scope (continued)

The range of current day missions used to lend credibility to this analysis effort are 5 day direct action missions and 11 day special reconnaissance (RECON) performed by Special Forces personnel.

The cost benefit analysis used a 20 year investment window for purposes of life-cycle costing. This period was chosen primarily because the solar panel warranty period was for this same time period as well.

Because Army communications equipment requires 70% of the Army's small battery inventory, this study employed items such as the Single Channel Ground and Airborne Radio System (SINCGARS) as the primary measuring tool.

1.12 Essential Elements of Analysis (MOE)

What are the weight trade-offs between the status quo battery regimen versus the newer rechargeable batteries BB-390U and BB-2590? (lbs.)

What is the life-cycle cost savings between current "throw away" batteries used by the Army versus rechargeables charged by solar or fuel cells? ($$$)

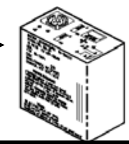
What % of the 20 year life-cycle costs are for battery disposal? (% of total $$$)

Figure 12. Essential Elements of Analysis (MOE)

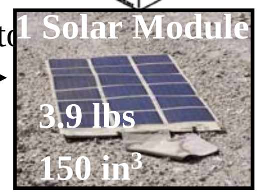
These are the questions to be answered by this analysis with the units of measure provided in following parenthesis..

1.13 Power and Energy Sources

1. Battery Cost Data. Bren-tronics (battery mfg) to provide 231 x BB-2590 rechargeable batteries



2. Solar Module Cost Data. Global Solar Energy (solar mfg) to provide 55 solar modules



53w Solar Charger

3. Fuel Cell Cost Data. Giner Electrochemical to provide a Direct Methanol Fuel Cell (fuel cell fuel is “windshield washer fluid”, 40ml methyl alcohol + 1000ml H2O)


150w DMFC

4. Cost-benefit analysis. *Compare the **3** systems*: (1) Status Quo BA-5590 battery, (2) Rechargeables BB-2590 and BB-390U with solar charger cost outcomes (3) Direct methanol fuel cells (DMFC, 150w) charging the BB-2590 for cost outcomes
5. Preliminary SOFTER cost benefit documentation. 1 Mar ‘04
6. Operational analysis. Feedback from SOF, Airborne

Figure 13. Power and Energy Source Cost Data

The cost-benefit approach used costing data from a Logistics Integration Agency purchase of a substantial number of the solar packages plus the Bren-tronics BB-2590 lithium-ion batteries. This data helped to provide a realistic cost of systems with a built-in economy of scale. (e.g. acquisition of systems purchased in bulk will be cheaper than single-system acquisitions).

Likewise, bulk purchases of small fuel cells were employed.

1.14 Special Ops Energy Value-Added Approach

SOF Missions → Different Equipment → #'s of Batteries

Duration **Power**

- Analyze the following 3 battery types because (1) batteries for SINCGARS are an important end item (2) these batteries are the heaviest batteries in the soldier portable category
  - Lithium Ion battery (Li ion); BB-2590
  - Nickel Metal Hydride (NiMH); BB-390U
  - Lithium di-Sulfide ($LiSO_2$); Primary (disposable) BA-5590
- Employ USSOCOM Power Requirements Report as starting point
  - ? Direct Action and Special Recon missions
  - ? Mission dependent equipment (by number and type)
  - ? Mission duration
- Calculate weight differentials from the different batteries given solar and fuel cell charging sources

Figure 14. Special Operations Energy Value-Added Approach

One of the intents of this paper is to integrate the work done by Special Forces and Mr. McCune with the potential to charge batteries with photovoltaic thin-film arrays. At the time of the 2001 McCune SOF Report listed in the literature search, thin-film photovoltaics was only producing electricity from solar at about 3 ½ percent efficiency. Today (2005), thin-film is producing average array efficiencies of about 11 percent*.

The second up-date that this report performs is to examine the new Lithium-ion; BB-2590 rechargeable battery against the older BB-390 NiMH rechargeable (noted in the SOF report). Li-ion weighs almost the same as the disposable BA-5590 but has 1/3rd less stored energy (in terms of amp hours). This report will examine these trade-offs in a cost benefit approach.

*To the reader: A good reference figure for solar efficiencies comes from the National Renewable Energy Laboratory (Golden, CO). NREL uses the figure of about 1,000 watts of power available from the sun at sea level. Therefore a device that is able to translate this power at an efficiency of 10% would be able to convert about 100 watts of the available 1,000.

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1.15 SOF Study – Notional Missions

Special Operations Forces

Direct action mission (16 man seal team, 5 day mission) is limited in duration and scope and may include:

- conduct a direct assault
- provide precision terminal guidance
- conduct standoff attacks by fire
- conduct independent sabotage

Special Reconnaissance mission (6 man team, 11 day mission):

- contact underground & assess resistance potential
- collect strategic political, economic, psychological or military intel
- collect critical enemy military order of battle
- collect technical military intelligence
- target acquisition and surveillance
- locate hostages, detained personnel or prisoners of war
- post strike Recon

Figure 15. SOF Study – Notional Missions

These are the two missions that the SOF Mission Analysis (2001) generated data for and by which we will compare battery weight and power value added potentials.

Note that the major difference between the two missions is mission duration. The Direct Action Mission requires a 5 day scenario whereas the Special RECON mission requires 11 days.

The hypothesis here is that photovoltaics will provide the longer mission with more value because of the duration away from grid power and energy from which recharging can occur.

1.16 Methodology

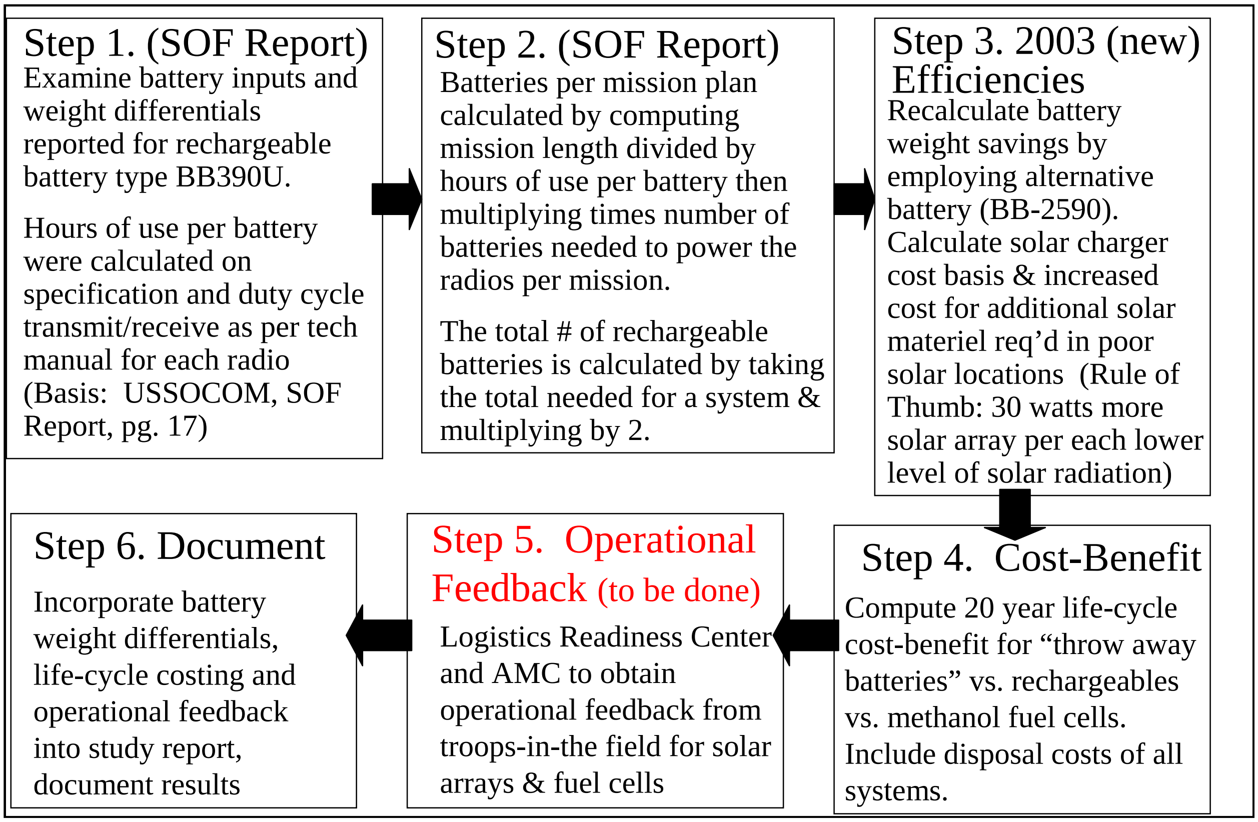


Figure 16. Methodology

The methodology is a 6 step process that uses the data supplied by the 2001 SOF Mission Analysis.

1.17 Assumptions

- Analysis outlined in USSOCOM Report "SOF Mission Analysis; Power Requirements" applies to current operations with communications equipment
  - follow-on work may consider power management for other equipment types
- Only solar option considered to recharge both types of rechargeable batteries BB-390U and BB-2590 (fuel is required for fuel cell option)
- No resupply available
- Geographical location allows for recharging of 1 BB-390
  - good solar; average solar radiation levels 1.85 – 2.95 tera watt hrs per km per year (e.g. Iraq, Ft. Irwin) = 1 BB-390 per ½ day, 1 BB-2590 per day
  - poor solar; average solar radiation levels 1.39 – 1.85 tera watt hrs per km per year e.g. (e.g. Graffenwoehr, Ft. Lewis) = X 2 solar array required for same output
- Batteries are an integral part of the solution
  - Power Source → Rechargeable Battery → Equipment
  - ~~Power Source →~~ Equipment

Figure 17. Assumptions

The primary assumption was to continue to supply power to Army equipment such as the SINCGARS radio by conventional battery means. This assumes that the SINCGARS radio will not operate directly from a "plug-in" or "on-board-power-generation-system" (such as a fuel cell).

2.18 Battery Weight Analysis

- BA-5590 disposable represents ~ 70% of batteries in army inventory (primary radio battery for PRC-119; SINCGARS)
- BB-390U (NiMH rechargeable) is heavier than the BA-5590 and has about ½ the amp hours
  - BB-2590 (Lithium ion rechargeable) is slightly heavier than the BA-5590 and nearly 2/3 the amp hours
- All competed batteries are the same volume for power engineering integration

Battery Name	Type	Weight (lbs)	Energy (A-hrs)	Cost ($ /btry)	Cubes (in^3)
BA-5590	Throw Away	**2.25**	**15.0**	**$ 77**	55
BB-390U	**Recharge**	**3.80**	**7.2**	**$254**	**55**
BB-2590	**Recharge**	**3.00**	**9.6**	**$235**	**55**

Figure 18. Battery Weight Analysis

Battery weight analysis employs the weights listed under the column heading "Weight (lbs)" along with amp hour inputs.

2.19 Special Ops Commo Equipment Specifications

Radio (# / msn)	Freq	Radio Wgt (lbs)	Pwr (watts)	Peak Amps	Battery (# req / equip)
Direct Action Mission (16 man seal team, 5 Days)					
PRC-117F (1)	30-512	10	20	4	BA-5590 (2)
LST-5C (1)	225-400	9	22	4	BA-5590 (1)
PRC-104 (2)	2-30	16	20	4	BA-5590 (4)
MX-300 (16)	400-430	2	4	1	NiCd (16)
GPS (2)	n/a	2	n/a	.5	BA-5800 (2)
KY-99	n/a	6	3	.5	BA-5590 (1)
Special Recon Mission (6 man team, 11 Days)					
PSC-5 (2)	30-400	12	20	4	BA-5590 (2)
PRC-104 (1)	2-30	16	20	4	BA-5590 (4)
PRC-137 (2)	2-60	7	10	2	BA-5590 (1)
KL-43	n/a	2	n/a	.5	BA-3058 (aa)
KY-99	n/a	6	3	.5	BA-5590 (1)
PRC-112 (12)	n/a	1.5	2	.5	BA-5112 (1)
GPS (2)	n/a	2	n/a	.5	BA-5800 (2)

Figure 19. Special Ops Commo Equipment Specifications

Although the BA-5590 disposable battery is the most widely used battery in the Army today, it is used primarily within the SINCGARS (PRC-119) radio. Special Operations forces do use SINCGARS at base camps and other locations – but for this study and analysis, only the data from the report SOF Mission Analysis; Power Requirements was employed. These data can be seen in the above figure.

Other types of equipment (e.g. weapons, optics, range finders …) are employed for these missions, but only communications equipment and their battery requirement is analyzed further. The Special RECON and Direct Action missions noted above dictate the type of electronic communications equipment respectively employed.

2.20 SOF Battery & Equipment Match for Direct Action MSN

Equip & #	Purpose	Btry	wgt	cost	Rechargeable	wgt	cost
KY-99 (2)	Voice Encrypt	**BA5590 x1**	2.2	$77	BB390B/U	3.8	$254
PRC-104 (2)	HF	**BA5590 x2**	2.2	$77	BB390B/U	3.8	$254
LST-5C (1)	SATCOM/UHF	**BA5590 x1**	2.2	$77	BB390B/U	3.8	$254
PRC-117F (1)	VHF/FM	**BA5590 x2**	2.2	$77	BB390B/U	3.8	$254
MX-300 (16)	UHF	NiCd x16	.4	$1.50	N/A		

Example Calculation to Determine # of throw away batteries required for PRC-117F for 5 day, direct action mission:

$$\frac{\text{Mission duration (hours)}}{\text{Expected Use per Battery (hours)}} \times \text{\# of Msn Equipment (by type)} \times \text{\# of batteries required by Msn Equipment}$$

$$\frac{120}{18}\,(1)\,(2) = 14$$ Disposable batteries required for PRC-117F (5 day, direct action mission)

$$(1)\,(2)\,(2) = 4$$ Rechargeable batteries required for PRC-117F (5 day, direct action mission)

Figure 20. SOF Battery & Equipment Match for Direct Action MSN

This is the methodology employed within SOF Mission Analysis; Power Requirements for Direct Action Mission battery requirement calculation. The author assumes a "worst case scenario" in that no re-supply is available. The bottom line for this methodology is that the example calculation employs 14 disposable batteries for the PRC-117F (example) and 4 batteries rechargeable batteries for the PRC-117F. A marked and significant difference – made possible by the recharging capability of the BB390B/U. Weight calculations are calculated later in this paper for the more advanced rechargeable; BB2590 (Lithium-ion)

The author also assumes that a method to recharge the rechargeable batteries is available and that it is sufficient to charge within mission constraint timelines. Further, because of the recharge capability of the BB-390B/U, the rule of thumb employed was that one battery is in use while the other is being recharged.

Expected hours of use per battery (disposable calculations only) were calculated based on specification and duty cycle transmit/receive as per the technical manual for each radio.

Similar calculations for the remaining electronic communications equipment to determine differences between disposable and rechargeable battery requirements are left to the reader.

2.21 SOF Battery & Equipment Match for Special Recon MSN

Equip & #	Purpose	Btry	wgt	cost	Rechargeable	wgt	cost
PSC-5F (2)	SATCOM/UHF	**BA5590 x2**	2.2	$77	BB390B/U	3.8	$254
KY-99 (1)	Voice Encrypt	**BA5590 x1**	2.2	$77	BB390B/U	3.8	$254
PRC-104 (1)	HF	**BA5590 x2**	2.2	$77	BB390B/U	3.8	$254
KL-43 (2)	Data Burst Trans	BA3058 x4	.1	$ .20	HHR150-AA	.2	$ .80
PRC-112 (12)	Survival Radio	BA5112 x1	.1		N/A		
PRC-137 (2)	HF Data	**BA5590 x1**	2.2	$77	B390B/U	3.8	$254
GPS (11)	Navigation	BA5800 x1	.5	$20	BB557	.7	$ 30

SOF calculation to determine number of rechargeables required is "rule of thumb": Multiply the number of batteries required by the specific equipment times the total number of the equipment. Multiply this resultant product times 2. This assumes one battery is in use while another is recharging.

$$(2)(2)(2) =$$ 8 rechargeable batteries required for PSC-5F for Special Recon mission

Figure 21. SOF Battery & Equipment Match for Special Recon MSN

This is the methodology employed within <u>SOF Mission Analysis; Power Requirements</u> for Special Reconnaissance Mission battery requirement calculation. The author assumes a "worst case scenario" in that no re-supply is available. The bottom line for this methodology is that the PSC-5F example calculation (264 / 29) x 2 x 2 = 36 employs "36"disposable batteries, rounded up (see previous page for methodology) and 8 rechargeable batteries for the same PSC-5F. The significant difference of 28 batteries (e.g. 36 – 8) generates a large weight savings differential. This will be high lighted on the next two figures.

2.22 SOF Report: BB-390U vs BA-5590 Weight Differential Analysis

Disposables

5 day, Direct Action Msn Radio	Hrs of use / btry / system	# btrys / msn	11 day, Spec Recon Msn Radio	Hrs of use / btry / system	# btrys / msn
PRC-117F	18	14 (31 lbs)	PSC-5F	29	36 (79 lbs)
LST-5C	18	7 (15 lbs)	PRC-137	18	29 (64 lbs)
PRC-104	18	28 (62 lbs)	PRC-104	18	29 (64 lbs)
MX-300	10	32 (13 lbs)	KL-43	24	88 (8 lbs)
KY-99	18	14 (31 lbs)	KY-99	53	5 (11 lbs)
Totals	**82**	**95 (152 lbs)**	PRC-112	20	24 (5 lbs)
			GPS	24	11 (5 lbs)
			Totals	**186**	**222 (236 lbs)**

Rechargeables

Same Direct Action Msn BB-390U			Same Special Recon Msn		
PRC-117F	10	4 (15 lbs)	PSC-5F	10	8 (31 lbs)
LST-5C	10	2 (8 lbs)	PRC-137	10	4 (15 lbs)
PRC-104	10	8 (31 lbs)	PRC-104	10	4 (15 lbs)
MX-300	10	32 (13 lbs)	KL-43	18	16 (8 lbs)
KY-99	10	4 (16 lbs)	KY-99	10	2 (8 lbs)
Totals	**50[1]**	**50 (83 lbs)**	PRC-112	20	24 (5 lbs)
			GPS	24	11 (5 lbs)
			Totals	**102[1]**	**69 (87 lbs)**
△ 45 fewer batteries, 69 less lbs, 45% less wgt			△ 153 fewer batteries, 149 less lbs, 71% less wgt		

[1] Rechargeable

Figure 22. SOF Report: BB-390U vs BA-5590 Weight Differential Analysis

This figure illustrates the weight savings between the disposable battery BA-5590 and the rechargeable BB-390U. For the 5 day, Direct Action Mission, the difference between disposables and rechargeables is 45 fewer batteries amounting to a weight savings of 69 pounds.

The 11 day, Special RECON Mission provided a larger weight savings of 165 pounds primarily because of the extended time period.

2.23 BB-2590 vs. BA-5590 Weight Differential Analysis

Disposables

5 day, Direct Action Msn			11 day, Spec Recon Msn		
Radio	**Hrs of use / btry / system**	**# btrys / msn**	**Radio**	**Hrs of use / btry / system**	**# btrys / msn**
PRC-117F	18	14 (31 lbs)	PSC-5F	29	36 (79 lbs)
LST-5C	18	7 (15 lbs)	PRC-137	18	29 (64 lbs)
PRC-104	18	28 (62 lbs)	PRC-104	18	29 (64 lbs)
MX-300	10	32 (13 lbs)	KL-43	24	88 (8 lbs)
KY-99	18	14 (31 lbs)	KY-99	53	5 (11 lbs)
Totals	**82**	**95 (152 lbs)**	PRC-112	20	24 (5 lbs)
			GPS	24	11 (5 lbs)
			Totals	**186**	**222 (236 lbs)**

Rechargeables

Same DA Msn	BB-2590		Same SR Msn		
PRC-117F	10	4 (12 lbs)	PSC-5F	10	8 (24 lbs)
LST-5C	10	2 (6 lbs)	PRC-137	10	4 (12 lbs)
PRC-104	10	8 (24 lbs)	PRC-104	10	4 (12 lbs)
MX-300	10	32 (13 lbs)	KL-43	18	88 (8 lbs)
KY-99	10	4 (12 lbs)	KY-99	10	2 (8 lbs)
Totals	**50[1]**	**50 (67 lbs)**	PRC-112	20	24 (5 lbs)
			GPS	24	11 (5 lbs)
			Totals	**102[1]**	**69 (74 lbs)**

[1] Rechargeable

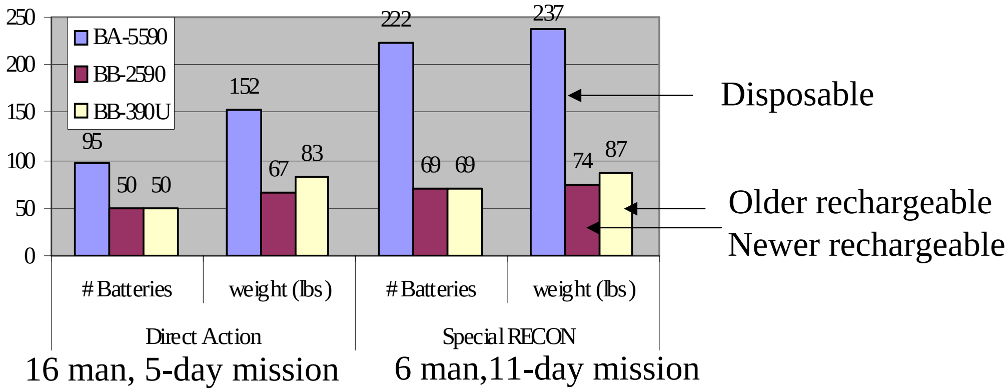
$\triangle$ 45 fewer batteries, 85 less lbs, 56% less wgt | $\triangle$ 153 fewer batteries, 162 less lbs, 69% less wgt

Figure 23. BB-2590 vs. BA-5590 Weight Differential Analysis

This case study analyses the weight savings by using the new lithium-ion BB-2590 rechargeable battery. Using the same scenarios from the previous figure, the weight savings for this rechargeable battery over the disposable is 85 less pounds for the 5 day Direct Action Mission and 163 fewer pounds for the 11 day Special RECON mission.

These are the same trends in weight savings as for the previous figure. However, weight savings by using the new BB-390U over the previous rechargeable (BB-390U) is 16 pounds saved for the 5 day Direct Action mission and 13 pounds saved for the 11 day Special RECON mission.

2.24 Battery Analysis Summary



- Employing rechargeables for 5 day missions reduces weight by between 45% (BB-390U) and 56% (BB-2590) and 1,800 in^3 (48% volume savings)
- 11 day missions leverage weight savings between 63% (BB-390U) and 69% (BB-2590) and in^3 by 6,120 (69% volume savings)
- Lbs per man battery weights of 9.5 (BA-5590), 5.1 (BB-390U), 4.2 (BB-2590) for direct action mission (16 man platoon)
- Lbs per man battery weights of 39.5 (BA-5590), 14.5 (BB-390U), 12.3 (BB-2590) for special Recon mission (6 man team)
- Reducing the number of disposable batteries also reduces disposal costs (calculated at $4/lb, the longer, 11 day mission would save $600 in battery disposal costs)

Figure 24. Battery Analysis Summary

This figure underscores the weight savings and battery savings exhibited when rechargeables are employed. Pounds per man are important to no one except the soldier who must carry this weight for long distances.

Conversations with Special Forces personnel indicate that many missions are undertaken where "it's hard to even stand up with all the weight". This would especially be the case for the Special RECON mission where each man would be expected to carry nearly 40 pounds of disposable batteries. But of course, as batteries are used up, they are most likely discarded and buried – rather than brought back to the base camp for disposal. This makes the mission lighter and lighter in battery weight as the end of the mission draws near.

Unfortunately, it could also be the case that in the event that a mission were to be extended while "in the field", with no re-supply of disposable batteries, communication would have to be "rationed" so as not to run out of battery power. This would probably not be the case for missions employing rechargeables.

2.25 Cost Benefit Analysis

- BA-5590 disposable represents ~ 70% of batteries in army inventory (primary radio battery for PRC-119; SINCGARS)
- BB-390U is about 2.5 times the cost of the disposable BA-5590
  - BB-2590 is becoming available to troops (cost is 2.4 times the BA-5590)
- All competed batteries are the same volume for power engineering integration

Battery Name	Type	Weight (lbs)	Energy (A-hrs)	Cost ($ /btry)	Cubes (in^3)
BA-5590	Throw Away	**2.25**	**15.0**	**$ 77**	55
BB-390U	**Recharge**	**3.80**	**7.2**	**$254**	55
BB-2590	**Recharge**	**3.00**	**9.6**	**$235**	55

Figure 25. Cost Benefit Analysis

This next section of the report deals with the cost and benefits exhibited by the batteries in question and for the power sources that provide energy to the rechargeables. Of particular interest in this section are the chart headings (see above figure) labeled “Battery Name”, “Type” and “Cost”.

2.26 Life Cycle Cost Analysis Assumptions

- Operate a single SINCGARS radio
- OPTEMPO of 1600 training hours / year
- 20 year economic life for solar array & direct methanol fuel cell
- 1 X BA-5590 used every two days (i.e. $77 every 48 hours)
- 1 X Solar Kit (code-name "Soldier Portable Power Pack" = SP4) will be comprised of
  - 1 X Solar Array (20 year warranty)
  - 3 X BB-2590 (rechargeable Li Ion batteries; replaced every 4 yrs)
  - 1 Charge controller (replaced every 4 yrs)
- 1 X Direct Methanol Fuel Cell employed (150W; replaced every 4 yrs)
- Methyl alcohol (for fuel cell) is available as packaged fuel
- Direct methanol fuel cell power integration exists
- Battery disposal costs are for CONUS only

Figure 26. Life Cycle Cost Analysis Assumptions

These are the assumptions used for this life-cycle cost analysis.

2.27 Economic Input: Life Cycle Costs

ITEM		Cost Types			
	Component Detail	Capital	Operation	Maintenance	Disposal
Solar Kit			per year	(or Replacement)	
	Array	$935	$0	$20	$0
	3 X Battery				1 X BA-5590 = $9
	either (BB-2590)	$705	$0	$705	1 X BB-2590 = $12
	or (BB-390U)	$762	$0	$762	1 X BB-390U = $15.2
				replace 4th year	$4/lb
	Charge Controller	$250		$250	$0
				replace 4th year	
Fuel Cell					
	Engine	$10,000	$67	$10,000	$0
	3 X Battery (above)			replace 4th year	
	Methyl Alcohol	$.50/gal	$16.75	n/a	$0
	(CH3OH)				
	Distilled H20	$1.58/gal	$50.25	n/a	$0
	Fan			$400	
	Fuel Mixing Pump			$150	
				Fan & Pump Replaced 4th Year	
Disposable	Battery (BA-5590)	$77		n/a	1 X BA-5590 = $9

Figure 27. Economic Input: Life Cycle Costs

The economic analysis is performed with current dollars for purposes of comparing the three alternatives:

1.150 watt, small fuel cell with rechargeable battery

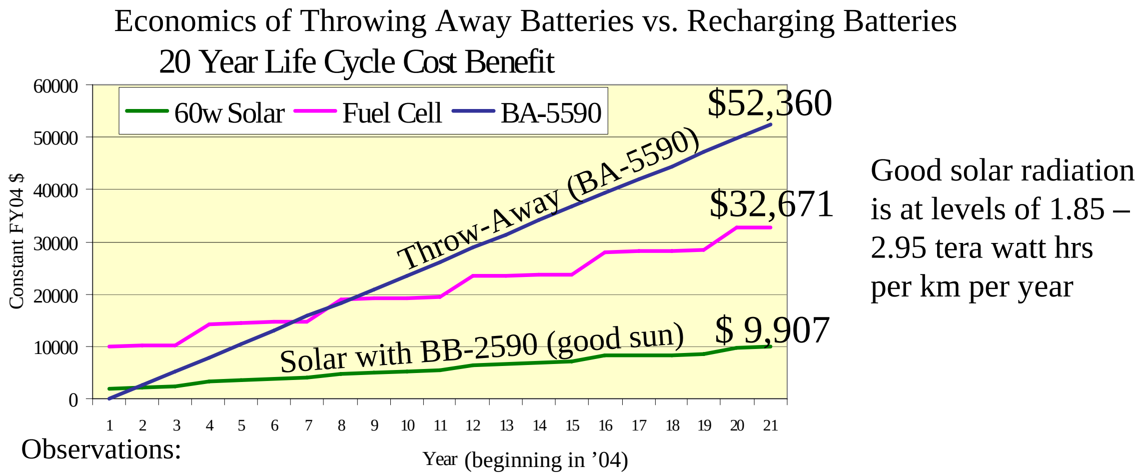
2.60 watt, photovoltaic thin-film array with rechargeable battery

3.Status quo, disposable battery

The economic inputs into the cost benefit process are illustrated above. Basically, total cost is represented by the summed component detail costs plus the recurring costs. Recurring costs are represented by operations maintenance and disposal costs.

Costs for transportation of batteries (from manufacturer, to transport hub, to theater) and disposal costs are not illustrated here. The reader should note that if these were included, the life cycle costs for disposable batteries would be considerably higher. Even though rechargeable batteries would eventually require disposal, the frequency of this operation would be much reduced as would the transport costs of rechargeable batteries.

2.28 Emerging Cost Analysis (Good Solar Locations)



Observations:

- At end of 20 year life cycle, throw away batteries are most expensive option
- Solar option is cheapest solution beginning 2nd year
- Payback for Direct Methanol Fuel Cell occurs about year 8 compared with BA-5590
- At the 20 year life-cycle, fuel cells are 3 times the cost of the solar option
- The 150 watt fuel cell, although not the cheapest solution has other operational benefits
  - Can charge continuously (day and night) as long as there's methanol
  - Will charge twice as fast as a single, 60 w solar panel

Figure 28. Emerging Cost Analysis (Good Solar Locations)

Holding dollars constant over a twenty year investment period, throw-away batteries become the most expensive option over the 20 year life cycle. The least cost alternative is the photovoltaic system with BB-2590 lithium-ion batteries.

Note: As discussed earlier no disposal costs nor transportation costs were considered in this graph.

2.29 Poor Solar Location Weight Differentials

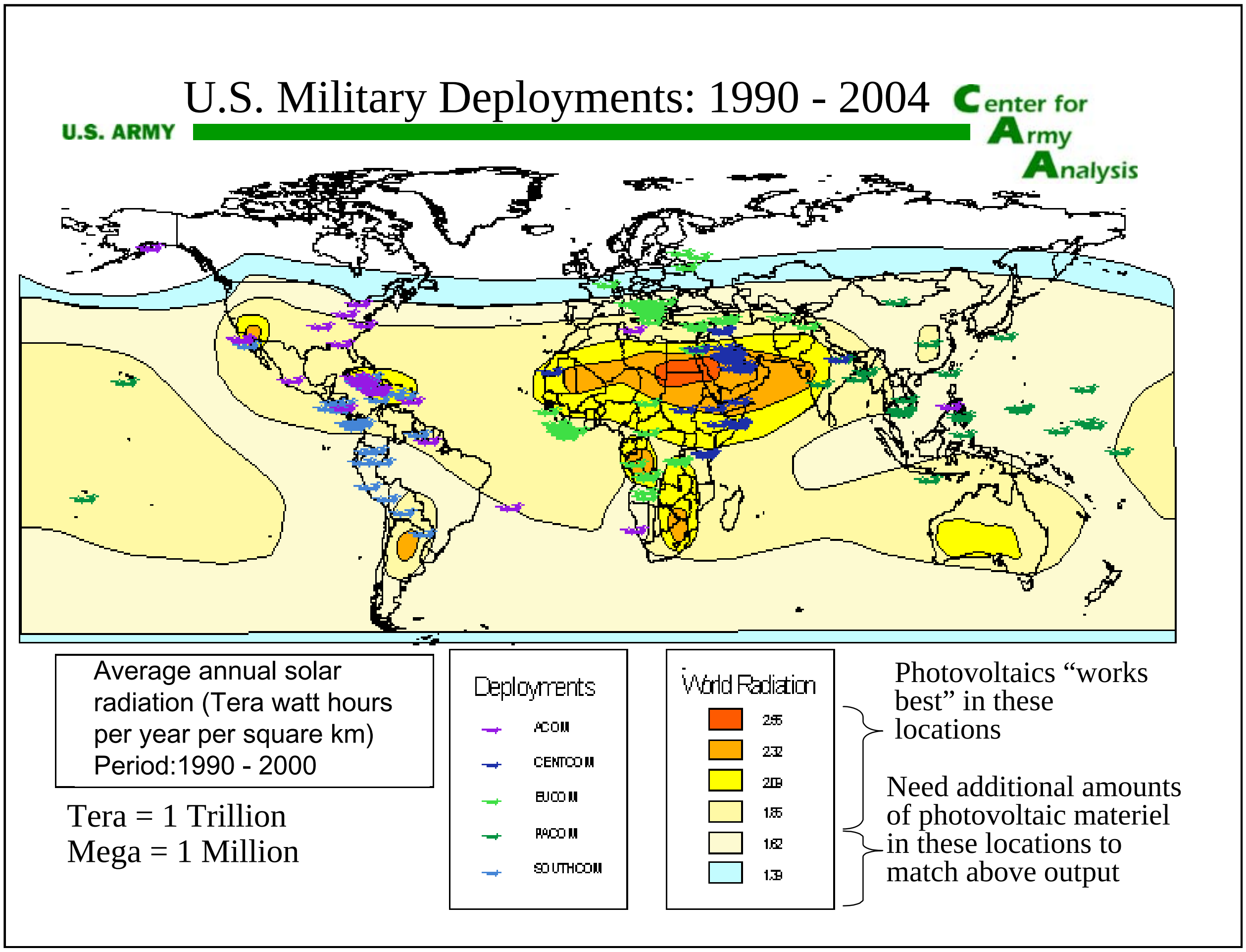


Figure 29. Poor Solar Location Weight Differentials

Photovoltaic power depends on receiving photons from the sun in order to work. Sun energy is different depending on geographic location and altitude. Therefore, assuming the same size PV array, the electrical power that PV produces also varies depending on location and altitude. Areas nearer the equator provide more photon energy for the PV effect than either the north or south pole. Likewise, increasing altitude also increases the output from PV arrays. In other words, to produce the "same" power output, at different altitudes, one would have to have a larger array at sea level to produce the same power that a smaller array could produce at 2,000 feet altitude.

The above figure provides an illustration of the annual solar radiation over the earth for the period 1990 through 2000. Superimposed on this solar mapping are US military deployments from 1990 through 2004.

Given that PV would tend to provide more power per square meter of array face in countries like Iraq (yellow scale) and less in Germany (blue scale), then this should be considered in the cost-benefit analysis because of increased benefit (more power) in countries with higher solar radiation and increased cost (requiring more PV array materiel) in countries with lower solar radiation. The following analysis examines this phenomena.

2.30 Emerging Cost Analysis (Poor Solar Locations)

- Assume that in poor solar locations - solar radiation levels 1.39 – 1.85 tera watt hrs per km per year, twice the solar materiel will be required (120 watt solar panels in lieu of 60 watt solar panels
- Additional solar array cost of $935 increases solar kit life cycle costs by 8.6%
- Additional solar array adds 4 lbs (150 in^3) to the soldier's load
- No change in ranking because of increased solar array cost

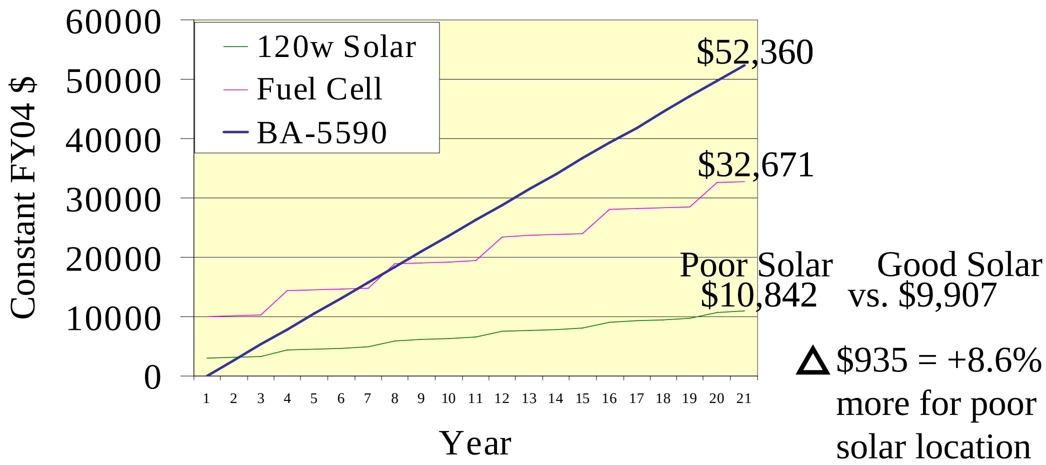


Figure 30. Emerging Cost Analysis (Poor Solar Locations)

Comparing twice the amount of solar array in a low solar country like Germany, with the costs previously calculated (see previous figure) for a good solar location such as Iraq yields these results. Poor solar locations would require approximately an 8.6% increase in cost investment.

Note: As discussed earlier, no disposal costs nor transport costs were considered in this graph.

2.31 Battery Disposal Analysis

- SOF Report mission comparing BA-5590 disposables to BB-2590 rechargeables:
  - Direct Action (5 day) mission use 45 fewer batteries
  - Translates to battery disposal cost savings of $180
  - Special Recon (11 day) mission uses 53 fewer batteries
  - Translates to battery disposal cost savings of $612
- 20 year life cycle costing illustrates the following disposal costs
  - 667 disposables (2.25 lbs/btry) ($4 disposal/btry) = $6,003
  - 18 BB-2590 (3.00 lbs/btry) ($4 disposal/btry) = $ 216
  - 18 BB-390U (3.80 lbs/btry) ($4 disposal/btry) = $ 274
- Disposal costs as % of total cost
  - BA-5590 $6,003 / $52360 (disposable) = 11.4%
  - BB-2590 $ 216 / $ 9907 (Li ion rechargeable) = 2.2%
  - BB-390U $ 274 / $ 9907 (NiMH rechargeable) = 2.7%

Figure 31. Battery Disposal Analysis

Battery disposal analysis illustrates that because one uses more disposable batteries than rechargeables – the cost for battery disposal reduces to the same linear relationship. In other words, the more batteries used requires more dollars for disposal.

This figure shows that the BA-5590 would incur the highest disposal costs as a direct function of the weight of each battery thrown away, followed by disposal costs for the BB-390U, followed by disposal costs for the BB-2590.

2.32 Operational Feedback on Solar Chargers

Operational feedback provided to CERDEC throughout 2004 and consisted of the following 4 responses from SOCOM and XVIII AB Corps:

- **Ease of use**: "Easy, just laid it out. Tie downs unnecessary."
- **Weight / Size**: "The weight and volume folded was great, easily packed and lightweight."
- **Durability**: "Too short a time to be conclusive."
- **Value**:

"Lightweight, quiet, easy battery power in the field."

"A lot of extra power to run commo equipment."

"Only good for long term missions."

"If you don't have the time in a secure location to set the panels out, they're no good."

"If there's not another alternative, then solar panels are the only option."

"With enough BB2590's and SP4's we wouldn't need other batteries."

"Charging two batteries with one panel would help."

Figure 32. Operational Feedback on Solar Chargers

Operational feedback was obtained with the help of the US Army Communication and Electronics Command (CECOM) and the Army Materiel Command's (AMC) Field Assist Science and Technology unit. The comments of the solar charging unit were, in general, positive.

2.33 Operational Feedback on Rechargeable Batteries

Based on a single, 11 day rotation at the Joint Readiness Training Center (JRTC), Ft. Polk, LA the following report was made by the 1st Brigade, 82nd Airborne, XVIIIth AB Corps Signal Officer

Facts:

- 4,840 BA-5590 disposable batteries required for a single brigade combat team (BCT)
- This does not include BA-5590's for Opposing Force, Observer Controllers, Echelons Above Division and Divisional Units
- Utilized PP-8444 (charger) to charge BB-390s

Results:

- Using only rechargeable batteries to power BCT's critical systems was successful
- Power is the key and "must be maintained"

Figure 33. Operational Feedback on Rechargeable Batteries

BB-390 battery "only" comments were also included in the interest to fairly portray the older of the two rechargeables (the lithium-ion battery being the younger). In general, 1st Brigade, 82nd Airborne found no reason why their complete mission could not be completed with rechargeable batteries.

However, they do note that constant and continuous power supply must be maintained in order to use the rechargeable alternative.

2.34 Summary

• Reduced SOF portable battery weight (and battery volume) can be achieved with current technologies for specific SOF missions on the order of:

- at least 50% less battery weight and 50% reduced battery volume
- weight and volume reductions on a "per man" basis show similar results

• Numbers of batteries can be significantly reduced provided the appropriate remote power technologies are in place – along with rechargeable battery planning

• 20 year, life cycle costs illustrate that solar is ~1/5th the cost of disposable batteries and ~1/3rd the cost of a tactical fuel cell.

• The difference in cost between 60w and 120w of solar array material (additional up-front capital cost of $1,000, for poor solar locations) represents less than 10% of the total 20-year life-cycle cost of the rechargeable battery system.

• Disposal costs for the disposable BB-5590 are ~11% of total life cycle battery costs – rechargeables are 2-3%

• Operational feedback from soldiers is supportive of rechargeables and solar recharging alternatives

Figure 34. Summary

The trend in the Army is to use more and more rechargeables as evidenced by changing Army policy in favor of using rechargeables. However, the acquisition of large quantities of disposable batteries to support Operation Iraqi Freedom and Operation Enduring Freedom confuse the issue because it gives the appearance that disposables are the wave of the future. Although true that disposables represent the legacy army, the future army will have to be cost conscious enough to leverage "off-the-shelf" technologies that provide added value to missions both in wartime and in peacetime with little or no degradation to current capabilities. This is the essence of why the Army requires cost-benefit analysis for all future systems.

In addition to cost savings, rechargeable batteries offer the individual soldier additional value in significantly decreased weight and volume that he/she must carry into battle or on training missions.

Army environmental stewardship (espoused in AR-200-1) requires that hazardous materials be accounted for and disposed of properly. Soldiers do a good job of disposing of disposable batteries and are in the planning stages of implementing methodologies for disposing of rechargeables. (note: this involves a system of counting the number of cycles that a rechargeable battery has been "recharged", and continually being able to compare the current recharge cycle with the maximum recycle value of 300 per the rechargeable manufacturer; Brentronics, Comack, Long Island, NY)

Lastly and probably most important, troops in the field seem to support rechargeables and have gone through significant training exercises to measure the rechargeable system versus the disposable status quo. Solar, thin-film charging arrays are also supported by the solder both in terms of weight and volume and charging capacity.

3 RECOMMENDATIONS

(1) AMC-FAST study sponsors leverage their positions as "field assistance teams in science and technology" to collect first order data and feedback on a regular basis from troops-in-the-field and provide this data to analytical organizations for critical analysis and review.

(2) Provide a continuing economic life-cycle analysis of renewable power and energy generation sources on a yearly basis. This is needed as battery technologies improve and renewable power source manufacturing increases efficiencies and lowers cost through mass production. (note: Department of Energy studies indicate that the cost of photovoltaics, (as only 1 example) are reduced "on average" by 5 percent per year. Similarly thin-film photovoltaic product efficiencies have increased by nearly 2 percent each year since 1999.

(3) Continue to explore stored energy alternatives as they become commercially available but to also recognize their shortcomings.

Figure 35. Recommendations

The study sponsors for this effort are uniquely positioned to help leverage emerging science and technologies because of the very nature of their charter. Field Assistance in Science and Technology (FAST) advisors are positioned with every major Army command and include such organizations as United States Army Europe, European Command, US Army Southern Command, III Corps (Ft. Hood), XVIIIth Airborne Corps (Ft. Bragg) and others. Further, they have access to headquarters and commanders of these organizations with some budget authority. The work that AMC-FAST does on a daily basis puts them in touch with troops-in-the-field for many technical evaluations, feedback, data gathering and "gripe sessions".

Data and verbal feedback obtained soldiers from deployments of various kinds can be gathered by AMC-FAST advisors and provided to analytical Agencies for further analysis. First order data can be stored and sent on any number of electronic storage media and represents the best obtainable information that quality analysis relies on. In the past, AMC-FAST advisors have provided data to analysis organizations ranging from data card from equipment powering Tactical Operations Centers to verbal feedback direct from soldiers using specialized, prototypical equipment (e.g. fuel cells) for the very first time.

Equally important to data is the necessity to remain current with ever changing technologies such as those exhibited by power and energy initiatives. As power and energy technologies evolve to more compact, more efficient sizes, there often is an accompanying cost shift that can dramatically, in a short period of time, change previously computed cost-benefit analyses. However, analytical organizations must always keep in mind certain cause and effect relationships that exhibit untoward side effects having physical, economic or integrated complex relationships that need to be reviewed and reported as honestly and straight-forward as possible.

3.18 Glossary

Agency Acronymns:
USSOCOM: US Special Operations Command (Tampa, FL)
USAREUR: US Army Europe (Heidelberg, GE)
LRC: Logistics Readiness Center (Ft. Monmouth)
LTA: Logistics Transformation Agency (Ft. Belvoir)

Study Acronymns:
ADAPT: Analysis of Deployable Applications of Photovoltaics in Theater
REASR: Renewable Energy Analysis for Strategic Responsiveness
SOFTER: Special Operations Forces Tactical Energy Resource
SERIOUS-A: Strategic Energy Resource Investment Optimization – US Army
SP4: Soldier Portable Photovoltaic Power Packs

Energy Storage & Power Systems Acronymns:
BA-5590: Throw Away Lithium ($LiSO_2$) Battery, 2.3 lbs, 24 Volts
BB-390: Army Rechargeable Nickel Metal Hydride (NiMH) Battery, 3.8 lbs, 24 Volts
BB-2590: Army Rechargeable Lithium Ion Battery (Li-Ion), 3 lbs, 24 Volts
DMFC: Direct Methanol Fuel Cell (runs on “windshield wiper fluid”, a.k.a wood alcohol)
PEM: Proton Exchange Membrane Fuel Cell (runs on hydrogen)
PV: Photovoltaics, means *energy from the sun*
TQG: Tactically Quiet Generator (usually diesel or JP8)

Figure 34. Glossary

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APPENDIX A PROJECT CONTRIBUTORS

1. PROJECT TEAM

a. Project Director: Hugh W. Jones

b. Team Members: Dr. Charles Leake (deceased)

c. Other Contributors: Mr. Randy McCune, Mr. Tom Nycz, Mr. Dennis Lane, Ms. Elizabeth Bostic, Dr. Michael Quah, Mr. Nicholas Sifer, Giner Electrochemical Systems, LLC

2. PRODUCT REVIEWERS

Dr. Ralph E. Johnson, Quality Assurance

3. EXTERNAL CONTRIBUTORS (If any)

APPENDIX B USAREUR REQUEST FOR ANALYTICAL SUPPORT

REQUEST FOR ANALYTICAL SUPPORT

PART 1

Performing Division: RA | *Account Number:* 2003037

Tasking: | *Mode (Contract-Yes/No):* In-house

Acronym: SOFTER

Title: Special Operations Forces Tactical Energy Resource

Start Date: 10-Mar-03 | *Estimated Completion Date:* 01-May-03

Requestor/Sponsor (i.e., DCSOPS): USAREUR | *Sponsor Division:*

Resource Estimates: *a. Estimated PSM:* 1 | *b. Estimated Funds:* $0.00

c. Models to be Used: None

Description/Abstract:
The US Army is continuing to fight the global war on terrorism in remote areas of the globe. Army Special Operations Forces and light infantry troops are at the forefront of these operations in places like Kandahar, Kabul, the Phillipines, Yemen and Indonesia. They're using rechargeable battery power for much of their tactical operations in these remote areas.

Study Director/POC Signature: Hugh Jones | *Phone#:* 703-806-5389

Study Director/POC: Mr. Hugh Jones

PART 2

Background:
Significant advantages exist in using solar power to remotely recharge Army issued rechargeable batteries like the BB-390. Photovoltaic (PV) arrays are becoming more effective and efficient in the recharge process and provide lightweight, value-added for remote missions. What would be the cost and benefit to the US Army if SOF and light infantry forces began to employ solar chargers for their remote tactical operations.

Scope:
Limit the scope of work to Direct Action and Special Reconnaissance Mission types (notional) but employ all the typical SOF and light infantry systems requiring battery power for remote operations.

Issues:
Using USACECOM estimates for total battery consumption and battery charger alternatives for the forces in question, estimate the cost / benefit in purchasing solar chargers vs. conventional charging methods for SOF and light infantry units. Include savings to investment ratios, paybacks and disposable battery weights vs. rechargeable battery weights for the missions outlined above.

Milestones:
1. Examine the TOE that SOF forces take to the fight and match them with available off-the-shelf "throw away" batteries along with their rechargeable counterparts. 2. Analyze notional missions undertaken by SOF forces and match-up the types of battery powered equipment employed within these missions. 3. Determine value added that rechargeable batteries with solar power recharging can provide. (eg. Reduced weight, silent ops, etc.)

Signatures *Division Chief Signature:* David J Russo | *Date:* 19 FEB 2003

Division Chief Concurrence: Mr. David Russo

Sponsor Signature: John I. Johnson | *Date:* 21 Feb 2003

ponsor Concurrence (COL/DA Div Chief/GOSES): USAREUR

Entry Date: 05-Nov-02 *Print Date:* 12-Feb-03

APPENDIX C USSOCOM REQUEST FOR ANALYTICAL SUPPORT

REQUEST FOR ANALYTICAL SUPPORT

PART 1

Performing Division: RA | ***Account Number:*** 2003037

Tasking: | ***Mode (Contract-Yes/No):*** In-house

Acronym: **SOFTER**

Title: Special Operations Forces Tactical Energy Resource

Start Date: 10-Mar-03 | ***Estimated Completion Date:*** 01-May-03

Requestor/Sponsor (i.e., DCSOPS): ~~[illegible]~~ USSOCOM | ***Sponsor Division:*** SOAL-T

Resource Estimates: | ***a. Estimated PSM:*** 1 | ***b. Estimated Funds:*** $0.00

c. Models to be Used: None

Description/Abstract:

The US Army is continuing to fight the global war on terrorism in remote areas of the globe. Army Special Operations Forces and light infantry troops are at the forefront of these operations in places like Kandahar, Kabul, the Phillipines, Yemen and Indonesia. They're using rechargeable battery power for much of their tactical operations in these remote areas.

Study Director/POC Signature: [illegible] | ***Phone#:*** 703-806-5389

Study Director/POC: **Mr. Hugh Jones**

PART 2

Background:

Significant advantages exist in using solar power to remotely recharge Army issued rechargeable batteries like the BB-390. Photovoltaic (PV) arrays are becoming more effective and efficient in the recharge process and provide lightweight, value-added for remote missions. What would be the cost and benefit to the US Army if SOF and light infantry forces began to employ solar chargers for their remote tactical operations.

Scope:

Limit the scope of work to Direct Action and Special Reconnaissance Mission types (notional) but employ all the typical SOF and light infantry systems requiring battery power for remote operations.

Issues:

Using USACECOM estimates for total battery consumption and battery charger alternatives for the forces in question, estimate the cost / benefit in purchasing solar chargers vs. conventional charging methods for SOF and light infantry units. Include savings to investment ratios, paybacks and disposable battery weights vs. rechargeable battery weights for the missions outlined above.

Milestones:

1. Examine the TOE that SOF forces take to the fight and match them with available off-the-shelf "throw away" batteries along with their rechargeable counterparts. 2. Analyze notional missions undertaken by SOF forces and match-up the types of battery powered equipment employed within these missions. 3. Determine value added that rechargeable batteries with solar power recharging can provide. (eg. Reduced weight, silent ops, etc.)

Signatures | ***Division Chief Signature:*** David J Russo | ***Date:*** 7 MAR 2003

Division Chief Concurrence: Mr. David Russo

Sponsor Signature: [illegible] | ***Date:*** 17 Mar 03

ponsor Concurrence (COL/DA Div Chief/GO/SES) : ~~USASOC~~ USSOCOM HQ

Entry Date: ***05-Nov-02***   ***Print Date:*** ***24-Feb-03***

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